Naval Postgraduate School
Monterey, California 93943-5138

NPS-09-02-004

SUMMARY OF RESEARCH 2000

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

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13. ABSTRACT (Maximum 200 words.)

This report contains project summaries of the research projects in the Department of Mathematics. A list of recent publications is also included, which consists of conference presentations and publications, books, contributions to books, published journal papers, and technical reports. Thesis abstracts of students advised by faculty in the Department are also included.

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THE NAVAL POSTGRADUATE SCHOOL MISSION

Increase the combat effectiveness of the U.S. and allied forces and enhance the security of the U.S.A. through advanced education and research programs focused on the technical, analytical, and managerial tools needed to confront defense related challenges of the future.

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PREFACE

Research at the Naval Postgraduate School is carried out by faculty in the four graduate schools (School of International Graduate Studies, Graduate School of Operations and Information Sciences, Graduate School of Engineering and Applied Sciences, and Graduate School of Business and Public Policy) and three Research Institutes (The Modeling, Virtual Environments, and Simulation (MOVES) Institute, Institute for Information Superiority and Innovation (I2SI), and Institute for Defense System Engineering and Analysis (IDSEA). This volume contains research summaries for the projects undertaken by faculty in the Department of Mathematics during 2000. The summary also contains thesis abstracts for those students advised by Mathematics faculty during 2000.

Questions about particular projects may be directed to the faculty Principal Investigator listed, the Department Chair, or the Department Associate Chair for Research. Questions may also be directed to the Office of the Associate Provost and Dean of Research. General questions about the Naval Postgraduate School Research Program should be directed to the Office of the Associate Provost and Dean of Research at (831) 656-2099 (voice) or research@nps.navy.mil (e-mail). Additional information is also available at the RESEARCH AT NPS website, http://web.nps.navy.mil/~code09/

Additional published information on the Naval Postgraduate School Research Program can be found in:

- *Compilation of Theses Abstracts:* A quarterly publication containing the abstracts of all unclassified theses by Naval Postgraduate School students.
- *Naval Postgraduate School Research*: A tri-annual (February, June, October) newsletter highlighting Naval Postgraduate School faculty and student research.
- *Summary of Research*: An annual publication containing research summaries for projects undertaken by the faculty of the Naval Postgraduate School.

This publication and those mentioned above can be found on-line at:
http://web.nps.navy.mil/~code09/publications.html.

INTRODUCTION

The research program at the Naval Postgraduate School exists to support the graduate education of our students. It does so by providing military relevant thesis topics that address issues from the current needs of the Fleet and Joint Forces to the science and technology that is required to sustain the long-term superiority of the Navy/DoD. It keeps our faculty current on Navy/DoD issues, to maintain the content of the upper division courses at the cutting edge of their disciplines. At the same time, the students and faculty together provide a very unique capability within the DoD for addressing warfighting problems. Our officers must be able to think innovatively and have the knowledge and skills that will let them apply technologies that are being rapidly developed in both the commercial and military sectors. Their unique knowledge of the operational Navy, when combined with a challenging thesis project that requires them to apply their focused graduate education, is one of the most effective methods for both solving Fleet problems and instilling the life-long capability for applying basic principles to the creative solution of complex problems.

The research program at the Naval Postgraduate School consists of both reimbursable (sponsored) and institutionally funded research. The research varies from very fundamental to very applied, from unclassified to all levels of classification.

- Reimbursable (Sponsored) Program: This program includes those projects externally funded on the basis of proposals submitted to outside sponsors by the School's faculty. These funds allow the faculty to interact closely with RDT&E program managers and high-level policymakers throughout the Navy, DoD, and other government agencies as well as with the private sector in defense-related technologies. The sponsored program utilizes Cooperative Research and Development Agreements (CRADAs) with private industry, participates in consortia with government laboratories and universities, provides off-campus courses either on-site at the recipient command, by VTC, or web-based, and provides short courses for technology updates.

- Naval Postgraduate School Institutionally Funded Research (NIFR) Program: The institutionally funded research program has several purposes: (1) to provide the initial support required for new faculty to establish a Navy/DoD relevant research area, (2) to provide support for major new initiatives that address near-term Fleet and OPNAV needs, (3) to enhance productive research that is reimbursably sponsored, and (4) to cost-share the support of a strong post-doctoral program.

In 2000, the level of research effort overall at the Naval Postgraduate School was 137 faculty work years and exceeded $43 million. The reimbursable program has grown steadily to provide the faculty and staff support that is required to sustain a strong and viable graduate school in times of reduced budgets. In FY2000, over 93% of the research program was externally supported. A profile of the sponsorship of the Naval Postgraduate School Research Program in FY2000 is provided in Figure 1.

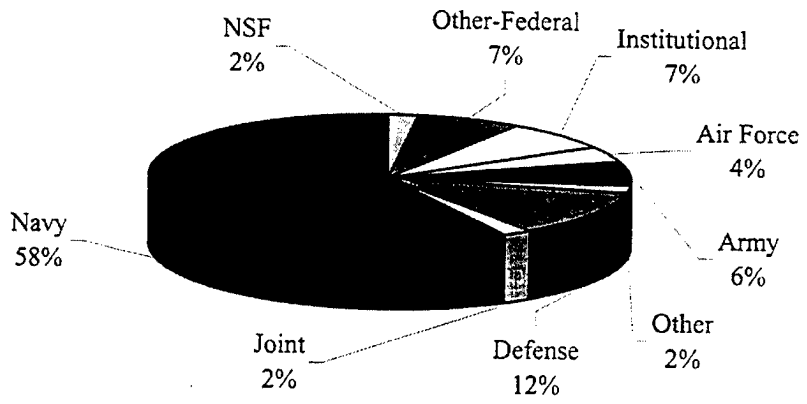


Figure 1. Profile of NPS Research and Sponsored Programs ($43M)

The Office of Naval Research is the largest Navy external sponsor. The Naval Postgraduate School also supports the Systems Commands, Warfare Centers, Navy Labs and other Navy agencies. A profile of external Navy sponsorship for FY2000 is provided in Figure 2.

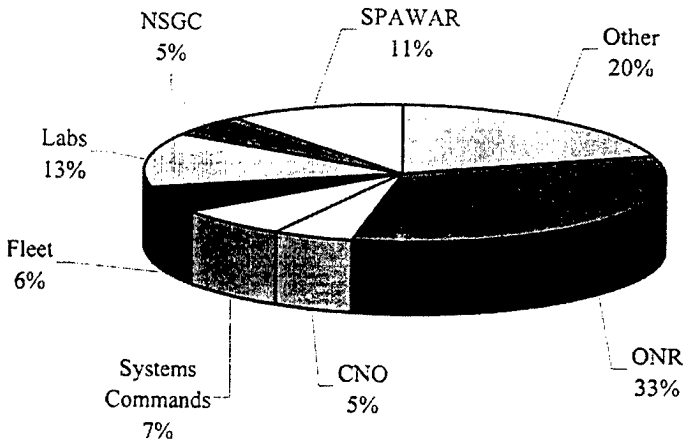


Figure 2. Navy External Sponsors of NPS Research and Sponsored Programs ($25M)

These are both challenging and exciting times at the Naval Postgraduate School and the research program exists to help ensure that we remain unique in our ability to provide education for the warfighter.

DAVID W. NETZER
Associate Provost and Dean of Research

December 2001

DEPARTMENT OF MATHEMATICS

MICHAEL MORGAN
CHAIR

DEPARTMENT SUMMARY

OVERVIEW:

The NPS Mathematics Department is committed to excellence. Our purpose is to provide an exceptional mathematical education focused on the unique needs of our students, to produce relevant research for our sponsors, and to provide quality service to the community. We further are committed to maintenance of a well-designed curriculum and a supportive environment for our students.

CURRICULA SUPPORTED:

- The majority of the departmental effort is devoted to the service courses offered which support a variety of curricula.

DEGREES GRANTED:

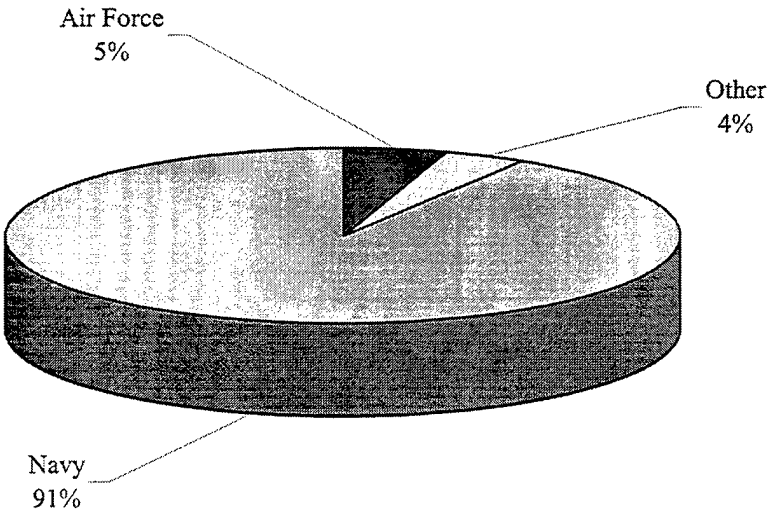
- Master of Science in Applied Mathematics
- Doctor of Philosophy

RESEARCH THRUSTS:

- Scientific Computation
- Control Theory
- Approximation
- Numerical Modeling

RESEARCH PROGRAM-FY2000:

The Naval Postgraduate School's research program exceeded $43 million in FY2000. Over 93% of the Naval Postgraduate School Research Program is externally funded. A profile of the external research sponsors for the Department of Mathematics is provided below along with the size of the FY2000 externally funded program.



Size of Program: **$303K**

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TOTAL LEAST SQUARES FITTING OF ORDERED DATA WITH POLYNOMIAL SPLINES

C.F. Borges, Associate Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: To develop fast and numerically stable algorithms for fitting polynomial splines to ordered data with minimal error in the total least-squares sense.

SUMMARY: This unfunded effort is a continuing research project. The idea is to fit parametric polynomial spline curves to ordered data to get the best possible fit. Unlike traditional least-squares methods we assume that errors may occur in both the x and y directions. Moreover, we allow the data to be completely general - in particular, it does not have to be functional in nature, it may overlap itself or change directions without restriction. All that is required is an ordered set of points in the plane. I have investigated a variety of different approaches and have developed some very fast and robust algorithms for solving the problem for a single Bezier curve. I have also started work on extending this approach to multi-segment Bezier curves with arbitrary continuity conditions.

DoD KEY TECHNOLOGY AREAS: Other (Scientific Computation)

KEYWORDS: Curve Fitting, Data Compression, Approximation Theory

RESEARCH IN THE STRUCTURAL DYNAMIC RESPONSE OF THE RAH-66 COMANCHE HELICOPTER

D.A. Danielson, Professor
Department of Mathematics
Sponsors: Comanche Program Office and Naval Postgraduate School

OBJECTIVE: For the calendar year 2000, the NPS Comanche Team used Dytran to model the effects of an internal explosion on three different structures. First, a square box was constructed with a centrally located charge to validate and gain early experience with Dytran. Second, a section of the Comanche tail cone (EMD phase) was constructed for future correlation studies to see if this area is survivable. Third, the forward tailcone of the Static Test Article (STA) was modeled to compare with results of recent live fire tests.

PUBLICATION:

Danielson, D. A., "Research in the Structural Dynamic Response of the RAH-66 Comanche Helicopter," Naval Postgraduate School Technical Report, NPS-MA-001-01, December 2000.

THESIS DIRECTED:

Stephan, A. H., "Computerized Ballistic Modeling of the Comanche Tailfan Shroud," Masters Thesis, Naval Postgraduate School, December 2000.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Helicopters, Airframes, Explosions, Computer Software

NUMERICAL TRAJECTORY OPTIMIZATION

F. Fahroo, Assistant Professor
Department of Mathematics
Sponsor: Draper Labs

OBJECTIVE: To solve trajectory optimization problems that arises in astronautics by spectral collocation method.

SUMMARY: The purpose of this study was to investigate different spectral collocation techniques to solve a variety of trajectory optimization problems. Both Legendre and Chebyshev polynomials were used as the basis functions for approximation of the states and control variables of the underlying optimal control problems and highly accurate results were obtained for solutions to problems in orbit maintenance, spacecraft launch and orbit transfer.

PUBLICATIONS:

Fahroo, F. and Ross, I.M., "Costate Estimation by a Legendre Pseudospectral Method, to appear in the *Journal of Guidance, Control and Dynamics,* Vol. 24, No. 2, 2001.

Fahroo, F. and Ross, I.M., "A Spectral Patching Method for Direct Trajectory Optimization," to appear in the *Journal of the Astronautical Sciences,* Vol. 48, No. 2/3, April-September 2000.

Fahroo, F. and Ross, I.M., "A Second Look at Approximating Differential Inclusions," *Journal of Guidance, Control and Dynamics,* Vol. 24, No. 1, 2001.

Fahroo, F. and Ross, I.M., "Direct Trajectory Optimization by a Chebyshev Pseudospectral Method," accepted in the *Journal of Guidance,* Control and Dynamics, September 2000.

Yan, H., Fahroo, F., and Ross, I.M., "Accuracy and Optimality of Direct Transcription Methods," *Proceedings of the AAS/AIAA Space Flight Meeting,* in Clearwater, FL, January 2000.

Fahroo, F. and Ross, I.M., "A Spectral Patching Method for Direct Trajectory Optimization," The Richard H. Battin Astrodynamics Symposium, College Station, TX, 20-21 March 2000, Paper AAS 00-260.

Fahroo, F. and Ross, I.M., "Direct Trajectory Optimization by a Chebyshev Pseudospectral Method," *Proceedings of the American Control Conference,* Chicago, IL, June 2000, pp. 3860-3864.

Fahroo, F. and Ross, I.M., "Trajectory Optimization by Indirect Spectral Collocation Methods," Proceedings *of the AIAA/AAS Astrodynamics Specialist Conference*, in Denver, CO, August 2000, pp. 123-129.

Yan, H., Fahroo, F., and Ross, I.M., "Optimal Feedback Control Laws by Pseudospectral Approximations," submitted to the American Control Conference 2001, September 2000.

PRESENTATIONS:

Fahroo, F., "Accuracy and Optimality of Direct Transcription Methods," presented at the AAS/AIAA Space Flight Meeting, in Clearwater, FL, January 2000.

Fahroo, F., "A Spectral Patching Method for Direct Trajectory Optimization," presented at the Richard H. Battin Astrodynamics Symposium, College Station, TX, 20-21 March 2000.

Fahroo, F., "Spectral Collocation Approximations for Optimal Control Problems," presented at the AMS 2000 Sectional Meeting, University of Louisiana at Lafayette, LA, 14-16 April 2000.

Fahroo, F., "Direct Trajectory Optimization by a Chebyshev Pseudospectral Method," presented at the American Control Conference, Chicago, IL, June 2000.

Fahroo, F., "Direct Trajectory Optimization by a Chebyshev Pseudospectral Method," presented at the American Control Conference, Chicago, IL, June 2000.

Fahroo, F., "Trajectory Optimization by Indirect Spectral Collocation Methods," presented at the AIAA-ASC 2000 Meeting, Denver, CO, August 2000.

THESIS DIRECTED:

Hallbach, L., "A Numerical Study of Fuel-Optimal Low Earth Orbit Maintenance," Masters Thesis, Naval Postgraduate School, December 2000.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: Costate Estimation, Optimal Control Theory, Legendre and Chebyshev Pseudo-spectral Method, Low-Earth Orbiting Spacecraft, Minimum Fuel Consumption

FORMATION CONTROL WITH AIR FORCE APPLICATIONS

Wei Kang, Assistant Professor
Department of Mathematics
Sponsor: Air Force Research Laboratory

OBJECTIVE: The objectives of the project are 1.The development of theoretical basis for the formation control of multiple vehicles: 2. Design controllers and STR projections for formations of spacecraft. 3. Coordinated control of orientation and pointing of multi-satellite systems. 4. Carry out simulations and experiments to test the formation control algorithm and the designed controllers.

SUMMARY: The PI visited AFRL on WPAFB for two weeks to collaborate with the AFRL research team in this subject. The design algorithm based on perceptive frame developed in NPS and MSU is combined with the sliding mode controller developed in AFRL. A joint paper with AFRL on satellite formation control is submitted to AIAA conference based on the collaboration.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: STR Projections, Formation Control Algorithm

VISIBLE SETS AND ITS MANUFACTURING APPLICATIONS

Wei Kang, Assistant Professor
Department of Mathematics
Sponsors: Ford Scientific Research Laboratory

OBJECTIVE: The focus of this project for the year of 2000 is on the production planning based on information feedback. The objective is to develop mathematical model for production planning taking the advantage of today's high-speed internet data transfer. The purpose of developing such model is to provide theoretical tools for analysis and automation for future B-to-B e-commerce in automotive and similar industries.

SUMMARY: Mathematical model of production planning integrating both statistical data and IT based fast information feedback is developed. A cost function is developed for dynamical production planning and adaptive optimization. Max-Plus algebra is used to model flexible production lines. The paper based on

this project won the "Best Paper Award" in the 6th International Conference on Control, Automation, Robotics and Vision held in Singapore in December 2000. The award is selected among about 360 papers published in the conference.

DoD KEY TECNOLOGY AREAS: Other (Mathematical Modeling)

KEYWORDS: Production Planning, B-to-B e-Commerce

COORDINATED FORMATION AND ATTITUDE CONTROL OF MULTI-SATELLITE SYSTEMS

Wei Kang, Assistant Professor
Department of Mathematics
Sponsors: Air Force Research Laboratory

OBJECTIVE: The objective of this project is to design a cooperative controller for the coordination of multiple satellites flying in formation. It includes the development of feedback for individual satellite, the coordination of multiple feedbacks, and coordination strategies for the relative attitude control of multiple satellites.

SUMMARY: Both sliding mode controller and H-infinity controller are developed for the attitude control of individual satellites. The proposed cooperative control is based on the perceptive frame. Some simulations show a significantly reduced overall tracking error. A conference paper and a journal paper are submitted as part of the product from this project.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: Attitude Control, Multiple Satellites

ENHANCED EM RADIATION SOURCE IMAGING

M. A. Morgan, Professor
Department of Mathematics
Sponsor: Office of Naval Research

OJBECTIVE: Multi-solution expansions will be combined with singular value decomposition to investigate optimized inverse scattering. Near-field data will be measured at the NRL test facility and used to experimentally validate the procedures developed here.

DoD KEY TECHNOLOGY AREAS: Sensors

KEYWORDS: Signatures, Spectral Decomposition

MAGNETIC FIELD SENSOR PLACEMENT

M. A. Morgan, Professor
Department of Mathematics
Sponsor: Office of Naval Research

OBJECTIVE: The major technical objective of this research is to investigate robust techniques for predicting spatial B-field signatures of elongated magnetic objects using vector field measurements near to the object. Of significant importance is development of a procedure for predicting the number and optimal

placement of the field sensors to attain a desired accuracy level in the presence of noise and other measurement errors.

SUMMARY: Fiscal Year 2000 progress involved: (1) development of the field generation program for the dipole enclosed in a hollow prolate spheroidal shell, and (2) initial evaluation of the least-squares field prediction algorithm for single mode test fields. Work during this first year's effort has involved only the m=0 axisymmetric field mode set.

PRESENTATIONS:

Morgan, M.A., "Near-Field Imaging Using Cylindrical Harmonic Back-Propagation," PIERS 2000, Cambridge, MA, 10 July 2000.

Morgan, M.A., "Null Spaces in Equivalent Current Field Generation," PIERS 2000, Cambridge, MA, 10 July 2000.

THESIS DIRECTED:

Yopp, Stacey, "Magnetic Field Sensor Placement," Masters Thesis, Naval Postgraduate School, June 2001.

DoD KEY TECHNOLOGY AREAS: Sensors, Modeling and Simulation

KEYWORDS: Near-Fields, Magnetic Field Imaging

IMPULSE ANTENNA MODELING

M. A. Morgan, Professor
Department of Mathematics
Sponsor: Naval Surface Warfare Center

OBJECTIVE: The goal of this task is to investigate the impulse radiation characteristics of specified antennas in the presence of buildings over real earth.

SUMMARY: Wire-grid numerical modeling of antenna and building structures has been completed using frequency-stepped calculations using GNEC. Impulsive near-fields within the modeled building is found using time-domain source modeling and inverse FFT convolution. Animations of fields within the structure are created using custom MatLab programs.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation

KEYWORDS: Impulse Response, Antenna Modeling, Near-Fields, GNEC

WIDEBAND LOW-PROFILE COMMUNICATION ANTENNA DESIGN

M.A. Morgan, Professor
Department of Mathematics
Sponsor: Army Research Office

OBJECTIVE: A finite element algorithm was developed for use in designing omnidirectional wideband VHF communication antennas having low-drag blister type profiles for use on helicopters.

SUMMARY: An analysis tool has been created for use in the design of efficient wideband VHF omnidirectional antennas for employment on Army helicopters. Dielectric loading can be used to optimize impedance matching and antenna pattern over a desired range of frequency. Tapered feed and flare

sections, without dielectric loading, provide impedance matching over ultra-wide bandwidths. The finite-element solution uses the coupled-azimuthal potential field formulation with mesh termination by the field-feedback technique. This software tool allows designers to optimize performance while constraining the antenna's physical profile through use of inhomogeneous lossy dielectric loading.

DoD KEY TECHNOLOGY AREAS: Sensors, Modeling and Simulation

KEYWORDS: Wideband, Finite Elements, Antenna Design

ATTITUDE DETERMINATION

B. Neta, Professor
Department of Mathematics
Sponsor: Unfunded

SUMMARY: Various k-vector range searching techniques are presented. These methods accomplish the range search by taking advantage of an n-long vector of integers, called the k-vector, to minimize the search time. The price is increased memory requirement for the k-vector allocation. However, it is possible to balance the extra memory required and the speed attained by choosing a step parameter h, which samples the k-vector. A two-level k-vector technique is also presented to minimize the speed of the admissible data identification associated with a given range. The proposed methods are compared with the well-known "binary search" technique, and demonstrate a high-speed gain rate (from 9 to more than 40 times). Finally, just to show one of the wide-range possible applications, a method to compute the *arcsin* function, based on the k-vector technique and a look-up table, is presented.

PUBLICATIONS:

Kluever, C.A., Neta, B., Hall, C.D., and Hanson, J.M., "Advances in the Astronautical Sciences," *Spaceflight Mechanics 2000,* Vol. 105, Univelt, Inc., San Diego, CA, 2000 (two-volume book).

Mortari, D. and Neta, B., "k-Vector Range Searching Techniques," *Proceedings AAS/AIAA Space Flight Mechanics Meeting*, Clearwater, FL, 23-26 January 2000, Paper Number AAS 00-128.

PRESENTATION:

Neta, B., "k-Vector Range Searching Techniques," AAS/AIAA Space Flight Mechanics Meeting, Clearwater, FL, 23-26 January 2000.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Space Vehicles, Modeling and Simulation

KEYWORDS: Attitude Determination, Search Algorithms

GPS TRAJECTORY AVERAGING

B. Neta, Professor
Richard Franke, Professor
Department of Mathematics
Sponsor: National Imagery and Mapping Agency

SUMMARY: Numerous independent sets of data have been taken or obtained. The steps in carrying out the required tasks are: partition sets of data into pieces that correspond to a particular part of a roadway and that have been taken using a single satellite configuration, select a portion of that path to be fit by a straight line or by a parametric cubic curve with continuous tangent vector, and compare the curves

obtained for independent sets of data over the same path to estimate the bias vector between the two. When these steps are performed for many independent tracks an estimate of the true bias can be obtained. Matlab programs have been written that perform each of the above tasks.

PUBLICATION:

Clynch, J.R., Franke, R., and Neta, B., "Improvements in Dynamic GPS Positions Using Track Averaging," *Proceedings of the ION Technical Meeting,* Anaheim, CA, 26-28 January 2000.

PRESENTATION:

Neta, B., "Improvements in Dynamic GPS Positions Using Track Averaging," ION Technical Meeting, Anaheim, CA, 26-28 January 2000.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: GPS, Bezier, Matlab

EFFICIENT NONLINEAR TRANSIENT DYNAMIC ANALYSIS FOR STRUCTURAL OPTIMIZATION USING AN EXACT INTEGRAL EQUATION FORMULATION

B. Neta, Professor
Department of Mathematics
J.H. Gordis, Associate Professor
Department of Mechanical Engineering
Sponsor: National Science Foundation

SUMMARY: The focus of this phase of the project is the development of an improved solution algorithm for fast transient analysis of large, locally nonlinear structures using time domain structural synthesis. Time domain structural synthesis is a general and exact formulation for transient problems in structural modification, substructure coupling, and base excitation. The formulation is characterized by the governing equation of the synthesis, which is a nonlinear Volterra integral equation. The governing equation makes use of impulse response functions calculated for those coordinates of the sub-structures subjected to forces of synthesis (e.g. modification forces, coupling forces). This physical coordinate formulation provides for a largely unrestricted and exact model reduction, in that only those coordinates of interest need be retained in the synthesis. We document the development of several algorithms intended to improve upon the original algorithm developed by Gordis. The last algorithm developed meets the stated goals of the project. This algorithm is a newly developed recursive, block-by-block convolution solution to the governing nonlinear integral equation. As is demonstrated with a simple but realistically large nonlinear base excitation problem (51,500 DOF finite element model), the new algorithm provides a 78% reduction in time required for the nonlinear transient base excitation solution, as compared with traditional direct integration calculated using a widely-used commercial finite element program. This very large savings in computer time is obtained for a single analysis, i.e. assuming no prior calculations have been made for the impulse response functions of the sub-structures. The new algorithm provides an even greater reduction in computer time for all subsequent analyses. As shown in the example problem, once all required impulse response functions have been calculated, the nonlinear base isolation solutions calculated using the new recursive, block-by-block convolution algorithm take approximately seven seconds, as compared with the direct integration solution, which takes approximately 30 minutes. This rapid reanalysis capability will facilitate the development of numerical optimization for the design of nonlinear isolation.

PUBLICATIONS:

Gordis, J. and Neta, B., "An Adaptive Method for the Numerical Solution of Volterra Integral Equations," *Recent Advances in Applied and Theoretical Mathematics*, N. Mastorakis, ed., World Scientific and Engineering Society International Conference, Athens, Greece, 1-3 December 2000, pp. 1-8.

Gordis, J. and Neta, B., "Fast Transient Analysis for Locally Nonlinear Structures by Recursive Block Convolution," *ASME Journal of Vibrations and Acoustics,* submitted for publication.

PRESENTATION:

Neta, B., "An Adaptive Method for the Numerical Solution of Volterra Integral Equations," World Scientific and Engineering Society International Conference, Athens, Greece, 1-3 December 2000.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Finite Elements, Structural Synthesis, Convolution, Block-by-Block, Adaptive

ORBIT DETERMINATION

B. Neta, Professor
Department of Mathematics
Sponsor: Unfunded

SUMMARY: Super implicit and Obrechkoff high order methods were compared for the solution of first and second order initial value problem. The second order problems of interest are those not containing first derivatives.

PUBLICATIONS:

Neta, B. and Fukushima, T., "Obrechkoff Versus Super-Implicit Methods for the Solution of First and Second Order Initial Value Problems," *Computers and Mathematics with Applications,* special issue on Numerical Methods in Physics, Chemistry and Engineering, T. E. Simos and G. Abdelas, eds., (accepted for publication).

Neta, B. and Fukushima, T., "Obrechkoff Versus Super-Implicit Methods for the Integration of Keplerian Orbits," *Proceedings of the AIAA/AAS Astrodynamics Specialist Conference*, Denver, CO, 14-17 August 2000, Paper Number AIAA 2000-4029.

PRESENTATION:

Neta, B., "Obrechkoff Versus Super-Implicit Methods for the Integration of Keplerian Orbits," AIAA/AAS Astrodynamics Specialist Conference, Denver, CO, 14-17 August 2000.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Orbit Determination, Initial Value Problems

DEPARTMENT OF MATHEMATICS

2000
Faculty Publications and Presentations

PUBLICATIONS/PRESENTATIONS

JOURNAL PAPERS

Fahroo, F. and Demetriou, M., "Optimal Actuator/Sensor Location for Active Noise Regulator and Tracking Control Problems," *Journal of Computational and Applied Mathematics,* Vol. 114, No. 1, 2000, pp. 137-158.

Kang, W., "Bifurcation Control Via State Feedback for Systems with a Single Uncontrollable Mode," *SIAM Journal of Control and Optimization*, 38, 2000, pp. 1428-1452.

Middlebrook, E.E., Mansager, B.K., and Borges, C.F., "A Brief Combat Simulation Analysis of Autonomous Legged Underwater Vehicles," *Military Operations Research,* Vol. 5, No. 1, January 2000, pp. 17-27.

CONFERENCE PAPERS

Chang, D.E., Kang, W., and Krener, A. J., "Normal Forms and Bifurcations of Control Systems," *Proceedings IEEE Conference on Decision and Control,* Sydney, Australia, 12-15 December 2000.

Clynch, J.R., Franke, R., and Neta, B., "Improvements in Dynamic GPS Positions Using Track Averaging," *Proceedings of the ION Technical Meeting,* Anaheim, CA, 26-28 January 2000.

Fahroo, F. and Ross, I.M., "A Spectral Patching Method for Direct Trajectory Optimization," The Richard H. Battin Astrodynamics Symposium, College Station, TX, 20-21 March 2000, Paper No. AAS 00-260.

Fahroo, F. and Ross, I.M., "Direct Trajectory Optimization by a Chebyshev Pseudospectral Method," *Proceedings of the American Control Conference,* Chicago, IL, June 2000, pp. 3860-3864.

Fahroo, F. and Ross, I.M., "Trajectory Optimization by Indirect Spectral Collocation Methods," *Proceedings of the AIAA/AAS Astrodynamics Specialist Conference,* Denver, CO, August 2000, pp. 123-129.

Gordis, J. and Neta, B., "An Adaptive Method for the Numerical Solution of Volterra Integral Equations," *Recent Advances in Applied and Theoretical Mathematics*, N. Mastorakis, ed., World Scientific and Engineering Society International Conference, Athens, Greece, 1-3 December 2000, pp. 1-8.

Hamzi, B., Kang, W., and Barbot, J.P., "On the Control of Hopf Bifurcations," *Proceedings IEEE Conference on Decision and Control,* Sydney, Australia, 12-15 December 2000.

Kang, W., Xi, N., and Sparks, A., "Theory and Applications of Formation Control in a Perceptive Referenced Frame," *Proceedings IEEE Conference on Decision and Control,* Sydney, Australia, 12-15 December 2000.

Kang, W., Sparks, A., and Banda, S., "Multi-Satellite Formation and Reconfiguration," *Proceedings American Control Conference,* Chicago, IL, 28-30 June 2000.

Kang, W., Xi, N., and Sparks, A., "Formation Control of Autonomous Agents in 3D Workspace," *Proceedings IEEE International Conference on Robotics and Automation,* San Francisco, CA, 24-28 April 2000.

Kang, W. and Song, M., "Manufacturing Planning Based on Information Feedback," *Proceedings 6th International Conference on Control, Automation, Robotics and Vision,* Singapore, 5-8 December 2000.

Mortari, D. and Neta, B., "k-Vector Range Searching Techniques," *Proceedings AAS/AIAA Space Flight Mechanics Meeting*, Clearwater, FL, 23-26 January 2000, Paper No. AAS 00-128.

Neta, B. and Fukushima, T., "Obrechkoff Versus Super-Implicit Methods for the Integration of Keplerian Orbits," *Proceedings of the AIAA/AAS Astrodynamics Specialist Conference*, Denver, CO, 14-17 August 2000, Paper No. AIAA 2000-4029.

Xiao, M. and Kang, W., "Bifurcation Control Using Integral Averaging Method," *Proceedings IEEE Conference on Decision and Control,* Sydney, Australia, 12-15 December 2000.

Yan, H., Fahroo, F., and Ross, I.M., "Accuracy and Optimality of Direct Transcription Methods," *Proceedings of the AAS/AIAA Space Flight Meeting,* Clearwater, FL, January 2000.

CONFERENCE PRESENTATIONS

Fahroo, F., "Accuracy and Optimality of Direct Transcription Methods," AAS/AIAA Space Flight Meeting, in Clearwater, FL, January 2000.

Fahroo, F., "A Spectral Patching Method for Direct Trajectory Optimization," Richard H. Battin Astrodynamics Symposium, College Station, TX, 20-21 March 2000.

Fahroo, F., "Spectral Collocation Approximations for Optimal Control Problems," AMS 2000 Sectional Meeting, University of Louisiana at Lafayette, LA, 14-16 April 2000.

Fahroo, F., "Direct Trajectory Optimization by a Chebyshev Pseudospectral Method," American Control Conference, Chicago, IL, June 2000.

Fahroo, F., "Direct Trajectory Optimization by a Chebyshev Pseudospectral Method," American Control Conference, Chicago, IL, June 2000.

Fahroo, F., "Trajectory Optimization by Indirect Spectral Collocation Methods," AIAA-ASC 2000 Meeting, Denver, CO, August 2000.

Morgan, M.A., "Near-Field Imaging Using Cylindrical Harmonic Back-Propagation," PIERS 2000, Cambridge, MA, 10 July 2000.

Morgan, M.A., "Null Spaces in Equivalent Current Field Generation," PIERS 2000, Cambridge, MA, 10 July 2000.

Neta, B., "Obrechkoff Versus Super-Implicit Methods for the Integration of Keplerian Orbits," AIAA/AAS Astrodynamics Specialist Conference, Denver, CO, 14-17 August 2000.

Neta, B., "k-Vector Range Searching Techniques," AAS/AIAA Space Flight Mechanics Meeting, Clearwater, FL, 23-26 January 2000.

Neta, B., "Improvements in Dynamic GPS Positions Using Track Averaging," ION Technical Meeting, Anaheim, CA, 26-28 January 2000.

Neta, B., "An Adaptive Method for the Numerical Solution of Volterra Integral Equations," World Scientific and Engineering Society International Conference, Athens, Greece, 1-3 December 2000.

CONTRIBUTION TO BOOK

Kluever, C.A., Neta, B., Hall, C.D., and Hanson, J.M., "Advances in The Astronautical Sciences," Spaceflight Mechanics 2000, Vol. 105, Univelt, Inc., San Diego, CA, 2000 (Two-Volume Book).

TECHNICAL REPORT

Danielson, D. A., "Research in the Structural Dynamic Response of the RAH-66 Comanche Helicopter," Naval Postgraduate School Technical Report, NPS-MA-001-01, December 2000.

DEPARTMENT OF MATHEMATICS

Thesis Abstracts

INVISCID AERODYNAMIC PREDICTIONS OF HYPERSONIC ELLIPTICAL PROJECTILES: A COMPARATIVE STUDY OF THE EFFECTS OF STABILIZING SURFACES

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Master of Science in Mathematics-June 2000
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Harris Edge, Weapons and Materials Research Directorate, U.S. Army Research Laboratory

With the advent of "smart" munitions, the U.S. and its allies are attempting to design more accurate tactical weapons. Of interest are relatively inexpensive barrel-launched projectiles capable of accuracy associated with guided munitions. This research studies potential configurations for a new class of kinetic energy projectiles.

From past research, it has been shown that projectiles with elliptical cross-sections are more stable in flight than those with circular cross-sections. This research looks at one particular shape, an elliptical cone, and numerically predicts the aerodynamic attributes in inviscid, steady, hypersonic flow. In particular, the effects of different stabilizing surface configurations are evaluated. A residual benefit of this research is to show that ZEUS, an afterbody solver typically used for missile design, is capable of providing solutions for these configurations.

The findings of this research will be delivered to the Chief, Aerodynamics Branch, Army Research Laboratory, and will fulfill part of ARL's commitment in a Key Technical Area agreement with the research laboratories of our allies.

DoD KEY YECHNOLOGY AREAS: Conventional Weapons, Modeling and Simulation

KEYWORDS: CFD, Inviscid, Aerodynamics, Hypersonic, Projectiles, Strakes, Flares

FORMATION CONTROL OF MULTI-SATELLITE SYSTEMS

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Fariba Fahroo, Department of Mathematics

The concept of satellite formation has been studied in recent years as a method of improving high-resolution imaging capability. In contrast to the relatively simple single satellite model, a more innovative control mechanism must be developed for the purpose of stability and accurate synchronization of multi-satellite systems. A two-satellite system is adopted as our test model because the design criteria for both the multi-satellite and two-satellite systems are similar. To generate a more realistic appraisal of our model, random noise and unexpected errors are incorporated in the simulations. In addition to modeling, a formation controller is designed. Simulations are carried out to check the formation stability and the performance robustness in the presence of tracking error and measurement noise. All the simulations are based on Simulink.

DoD KEY YECHNOLOGY AREA: Command, Control, and Communications

KEYWORDS: Satellite, Formation, Control

AGE REPLACEMENT POLICIES IN MULTIPLE TIME SCALES

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Samuel E. Buttrey, Department of Operations Research
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Craig W. Rasmussen, Department of Mathematics

We develop and estimate optimal age replacement policies for devices whose age is measured in multiple time scales. For example, the age of a jet engine can be measured in chronological time, the number of flight hours, and the number of landings. Under a single-scale age replacement policy, a device is replaced at age τ or upon failure, whichever occurs first. We show that a natural generalization to $k \geq 2$ scales is to replace non-failed devices when their usage path crosses the boundary of a k-dimensional region M, where M is a lower set with respect to the matrix partial order. For lifetimes measured in two scales, we consider two contexts. In the first, devices age along linear usage paths. For this case, we generalize the single-scale long-run average cost and estimate optimal two-scale policies. We show these policies are strongly consistent estimators of the true optimal policies under mild conditions, and study small-sample behavior using simulation. For the second context, in which device usage paths are unknown, we use two-dimensional renewal theory to derive the long-run average cost of a policy. We give examples in both settings and note that these ideas generalize to more than two scales.

DoD KEY TECHNOLOGY AREA: Other (Reliability)

KEYWORDS: Age Replacement, Multiple Time Scales, Renewal Theory

A BOUNDARY-LAYER MODEL OF THERMOCAPILLARY FLOW IN A COLD CORNER

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Doctor of Philosophy in Mathematics-June 2000
Dissertation Supervisor: David Canright, Department of Mathematics

A pool of liquid with a horizontal free surface is bounded on one side by a vertical solid wall, which is maintained at a cold temperature relative to the core flow region. Strong temperature gradients along the surface give rise to surface tension variations (thermocapillary stress), which drives flow. Thin viscous boundary layers form along the surface and wall. A boundary-layer model is designed which captures the dynamics of the cold corner, applicable for any Marangoni number M and Prandtl number P in the convective inertial regime.

Analytical expressions for the velocity and boundary-layer thicknesses are developed, which allow accurate prediction of the flow field. The core flow region (outside the viscous boundary layers) is treated as irrotational flow and Laplace's equation is solved using both a Green's function approach and a complex variables approach in the quarter-plane. The flow along the wall is treated as a plane wall jet.

The two-dimensional unsteady heat equation is solved using an alternating direction implicit method. Results show that the flow into the corner is strong enough to contain the thermal field, compressing the isotherms along the wall after steady-state is reached. Additionally, a uniform stream function prediction is developed, by matching the inner and outer flows, giving a relatively accurate depiction of the flow.

DoD KEY TECHNOLOGY AREAS: Materials, Processes, and Structures, Other (Applied Mathematics)

KEYWORDS: Thermocapillary Flow, Marangoni Number, Prandtl Number, Boundary Layer

AN EVALUATION OF HNeT (HOLOGRAPHIC QUANTUM NEURAL TECHNOLOGY) SOFTWARE PACKAGE

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Master of Science in Applied Mathematics-June 2000
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Second Reader: Bard K. Mansager, Department of Mathematics

This thesis investigates the properties of a software package called HNeT (Holographic/Quantum Neural Technology) which is based on the use of an artificial intelligence tool called Neural Networks. The basis for the investigation of this software is to establish its reliability, effectiveness and efficiency. Neural technology is a technological replication of the biological neural system designed to learn data patterns and process the data (stimulus) and then generate a response based on the memory of the data. HNeT theory is fundamentally different from the standard Artificial Neural System (ANS) in that it uses complex scalars to evaluate internal mappings of one set of values (stimuli) to another set of values (responses). HNeT employs a process known as *enfolding*, which allows the learning and subsequent recall of many stimulus-response associations to be compressed into a single HNeT neuron cell improving the speed of learning and recall accuracy as well as reducing storage requirements. Whereas the traditional ANS stores stimulus patterns separately as a reference template within a cell and are compared one at a time to a new incoming stimulus response pattern which in this case, requires larger amounts of memory.

DoD KEY TECHNOLOGY AREA: Computing and Software

KEYWORDS: Artificial Neural Networks, HNeT, Enfolding, Adaline, Madaline

MANUAL DIFFERENTIAL CORRECTION (MANDC)

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Master of Science in Space Systems Operations-September 2000
Advisors: David Canright, Department of Mathematics
Donald A. Danielson, Department of Mathematics

This thesis is a partial analysis of the Naval Space Command Manual Differential Correction (MANDC) software program. Through a process called Differential Correction, data collected from space surveillance radar observation stations is synthesized with previously composed element sets to maintain accurate orbital object position information. The Automatic Differential Correction (AUTODC) software program is central to this process. Unfortunately, AUTODC fails to converge 1.5% of the time. These failed observations are forwarded to MANDC for lengthy manual manipulation by the watchfloor operators. This thesis will provide an analysis of the MANDC program.

DoD KEY TECHNOLOGY AREA: Computing and Software

KEYWORDS: Nonlinear Least Squares, Differential Correction

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